TEST REPORT

SOUND ABSORPTION TESTS ON POLYURETHANE AND LIQUID SOAP FOAMS FOR ANECHOIC ENCLOSURES

by

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SUMMARY

An investigation was made of the normal and random incidence absorption of samples of 2-in thick polyurethane foam selected for use in the construction of an anechoic enclosure for lifting-fan noise studies.

Impedance tube measurements gave normal incidence absorption coefficients ranging from 0.38 at 500 c/s to 0.91 at 1500 c/s. Reverberation time measurements carried out at the NAE Acoustic Test Facility indicated a random incidence absorption coefficient of 0.79 at 500 c/s, increasing to almost 1.0 at 1250 c/s, after correction for diffraction effects.

Reverberation time measurements on 1-in, 2-in, and 4-in thick liquid soap foam showed high sound absorption. A 4-in thick foam gave a random incidence coefficient of 0.72 at 300 c/s to 1.0 at 800 c/s (not corrected for the effects of diffraction).

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1.0 INTRODUCTION

The Engine Laboratory of the DME has undertaken a preliminary program of fan-in-wing noise studies. To obtain meaningful results, the basic facility for noise studies required an anechoic chamber of suitable dimensions with a good anechoic termination for the high intensity sound. As the primary interest was in obtaining reliable results in the frequency range of 500 c/s to 10 Kc/s, a structure lined with 2-in thick, 80 ppi polyurethane foam was expected to give good absorption in the desired frequency range. The results of tests on separated layers of etched polyurethane foam (Ref. 1) also suggested favourable absorption qualities and the ability to survive high intensity sound for longer periods.

The impedance tube measurements (Ref. 2) on the liquid soap foam had shown highly promising sound absorption qualities. It seemed worthwhile to further explore the random absorption qualities of the liquid soap foam.

2.0 STANDARD TEST METHODS

The standard acoustic tests consist of finding the normal and random absorption coefficients of the material. The normal incidence absorption is found by mounting the specimen in an impedance tube and exploring the standing wave pattern excited by a single tone of a selected frequency. The random absorption coefficients were explored by measuring the decay time of sound with a known area of the material, in the reverberation room of the NAE Acoustic Test Facility.

2.1 Impedance and Absorption of Polyurethane Foam by the Tube Method

2.1.1 Definitions

The normal incidence sound absorption coefficient, α_n, of a material is the fraction of normally incident sound energy absorbed by the material. The absorption coefficient will, in general, depend on both the structure of the material and its method of mounting.

The ratio between pressure and normal fluid velocity at a point on the surface is called the acoustic impedance of the surface. The impedance may depend on the frequency of the incident wave and it may be complex, in which case the normal velocity is not in phase with the pressure. The normal absorption coefficient is related to the impedance of the material by

$$\alpha_n = 1 - \left[\frac{Z/\rho c - 1}{Z/\rho c + 1}\right]^2 \qquad (1)$$

where

Z is the impedance of the material

ρ is the density of air

c is the velocity of sound in air.

2.1.2 Impedance Tube and Method of Measurement

The normal absorption coefficients were measured in an impedance tube. The measuring technique employed here was that stipulated in ASTM Standards (C.384) (Ref. 3).

A schematic diagram of the impedance tube is shown in Figure 1. The impedance tube was of 3-7/8-in diameter and 100 cm in length, with rigid walls that transmitted or absorbed negligible sound energy.

A loudspeaker was mounted at one end of the tube and the specimen mounted, with rigid backing, at the other. The speaker, driven by a beat frequency oscillator, provided a source of longitudinal sinusoidal plane waves.

The standing wave pattern was explored in the tube by a movable microphone. The output from the microphone was fed to a constant percentage bandwidth frequency analyzer. The quantities measured were the maximum and minimum amplitudes of the standing wave pattern, D_1, the distance from the face of the specimen to the first minimum, and D_2, the distance between two successive minima, which was equal to the half wavelength, as shown in Figure 1.

Test frequencies chosen were 250, 400, 500, 750, 1000, 1250, 1500, 1750, and 2000 c/s. The high frequency limit was determined by the size of the impedance tube. The inside diameter of the tube should not be greater than the value $\frac{8000}{f_{max}}$, where f_{max} is the highest frequency for which measurements are desired. Larger diameter tubes would give rise to cross modes preventing the formation of plane waves.

2.1.3 Computation Method

The normal incidence absorption coefficient was calculated by

$$\alpha_n = \frac{4x}{(1+x)^2} \tag{2}$$

where x is the ratio of minimum to maximum amplitude of the standing wave. By using the standing wave ratio and $\frac{D_1}{D_2}$, the resistive and reactive components of the impedance were found by application of the well-known "Smith chart". Normal absorption coefficients were converted into more useful random incidence absorption coefficients by the empirical graph given by Zwikker and Kosten (Ref. 4).

The impedance measurements are presented in Table 1. The absorption coefficients are plotted in Figure 4 against the frequency.

2.2 Reverberation Method of Estimating Sound Absorption

In this method the absorption coefficient of a test specimen is determined by measuring the change in the decay rate of sound in the presence of a test specimen in a reverberation room.

Decay rate d is related to the total sound absorption A in a room by

$$A = 0.9210 \frac{vd}{c} \tag{3}$$

where v is the volume of air in the room

d is the rate of decay of sound pressure level in db/sec

c is the speed of sound in ft/sec.

If subscripts 1 and 2 are used to denote the conditions before and after the specimen has been placed in the reverberation room, the increase in the absorption coefficient is given by the difference.

$$A_2 - A_1 = \frac{0.9210}{c} (v_2 d_2 - v_1 d_1) \tag{4}$$

If the test specimen has an absorption coefficient of α_1 and covers an area S of a reverberation room having an absorption coefficient α_0, then the absorption coefficient of the specimen is given by

$$\alpha_1 = \frac{A_2 - A_1}{S} + \alpha_0 \tag{5}$$

2.2.1 Reverberation Time Measurements

Reverberation time measurements were conducted in the reverberation room of the NAE Acoustic Test Facility. The details of the reverberation room and instrumentation are reported in Reference 1. The sound field in the reverberation room was produced by two 15-in diameter loudspeakers driven by a beat frequency oscillator. The sound pressure levels were measured by two 1/2-in condenser microphones connected to a constant percentage bandwidth frequency analyzer. The output from the analyzer was connected to a noise level recorder. Two electrical contacts on the recorder were separated by 20 db and were energized by a wiper attached to the arm of the pen. The contacts were connected to the start and stop inputs of an electronic time counter.

Samples of the foam were placed in the centre portion of the floor of the reverberation room. The polyurethane foam sample tested was 6 ft × 4 ft × 2 in thick. The samples of the liquid foam tested had an area of 6 ft × 6 ft with the thickness of the foam varying from 1 to 4 in. Decay times were measured at three microphone stations for each one of a set of 1/3 octave band random noise, with mid-frequencies ranging from 250 c/s to 5000 c/s. The sound pressure levels in the reverberation room, before switching off the loudspeaker, were of the order of 95 to 115 db, depending on frequency.

In ASTM Standards C.423-60T (Ref. 3) it has been recommended that the number of samples of the reverberation time should be large enough to yield a mean reverberation time whose error is less than 1%. As the present tests were of a verifying nature, only a limited number of readings were taken.

The absorption coefficients were calculated by using equations (3) to (5).

2.2.2 Diffraction Effects

When the patch of specimen tested is relatively small, the effects of diffraction are likely to creep in, resulting in the measured absorption coefficients being dependent upon the size of the specimen. For small samples the measured absorption would be higher than the absorption coefficient of a sample occupying the whole area.

Northwood (Ref. 5) has discussed these effects and has computed the effects of diffraction for a range of values of conductance ratio g, susceptance ratio b, and Ka, which is a measure of the wavelength and size of the material ($K = \frac{2\Pi}{\lambda}$, and $a = \frac{cd}{c+d}$, where c and d are the dimensions of the rectangular patch). The conductance ratio g and susceptance ratio b can be obtained by impedance tube measurements and are given by

$$g = \frac{R}{R^2 + X^2}, \quad b = \frac{X}{R^2 + X^2} \tag{6}$$

where R and X are the resistive and reactive components, respectively.

Northwood's curves show that the absorption coefficient is strongly dependent on the values of Ka. In particular, the diffraction effects are dominant at lower values of Ka. The diffraction corrections applied were calculated as the ratio of the absorption coefficient for Ka = ∞ to the value of Ka in the desired frequency range.

The curves presented are limited to the values of b = -0.5 to +0.5 and g = 0 to 1.0. The results were extrapolated for the values of b and g for a small variation beyond the above range.

The diffraction corrections were applied only to the reverberation absorption coefficient of the 2-in thick polyurethane foam.

3.0 LIQUID SOAP FOAM TESTS

The liquid foam was made by whipping a known volume of equal parts of water and a synthetic liquid hand soap in a 45-gal drum until sufficient air had been incorporated to give an eight-fold volume increase and a foam density of approximately 0.125 g/cm^3. The beater was a 9-in diameter circular disk of 1/4-in mesh heavy wire screen, mounted radially at one end of a steel shaft, the other end being chucked in a 3/4-in heavy duty 375 rpm portable electric drill. After the foam had been prepared it was poured to the required depth into a 6-ft square trough, with 8-in high 16-gauge sheet metal sides, placed on the floor of the reverberation room.

It was noticed that in the course of a test, which took from 15 to 20 minutes, considerable draining of foam had occurred. The foam height fell, typically, about 1 in during the test using 4 in of foam, but it was also apparent that the foam density at the end of the test was much less than at the start. To get some idea of the amount of change in density that had occurred, some drainage time experiments were made in a 4-in diameter beaker, using the same liquid as in the reverberation tests. The results are shown in Figure 2.

The indication is that at the end of a 20-minute reverberation test the density of the liquid foam was probably only about one-sixth of its original value. This suggests that in any future work along these lines some effort should be made to reduce this rate of draining. It will be noted in Figure 2 that for the liquid soap used in the impedance tube experiment (Ref. 2), which was not available in quantity at the time the reverberation tests were made, the drainage rate was very much less than for the soap that was used in the reverberation tests.

4.0 TEST RESULTS

The normal and random absorption coefficients of the 2-in thick polyurethane foam are shown in Figure 4. Reverberation time measurements show (with diffraction effect corrections) that the absorption coefficient increases from 0.67 at 250 c/s to almost 1.0 beyond 1200 c/s. Normal absorption coefficients corrected to random incidence are generally lower than absorption coefficients computed from reverberation time measurements by more than 15% at 500 c/s to 10% at 1250 c/s.

The results of the liquid soap foam tests are presented in Figure 3. The random incidence absorption coefficient α is plotted against the frequency. The absorption coefficient of 1-in thick soap foam increases from almost 0 at 200 c/s to 0.55 at 600 c/s, decreases to 0.25 at 800 c/s, and again increases. Two-inch and 4-in thick foams do not show such marked peaks and troughs. The absorption coefficient increases as the thickness of the foam is increased from 1 to 4 in. The 4-in thick foam shows an absorption coefficient greater than 1.0 beyond 800 c/s, which is presumably due to the effects of diffraction. A 2-in thick liquid soap foam shows a substantial reduction in the absorption coefficient with a 1/2-hr drainage. This reduction is particularly high at the middle frequency range (600-1300 c/s). The reduction in absorption coefficient is nearly 50% around a frequency of 800 c/s.

5.0 DISCUSSION OF RESULTS

One may notice considerable difference in the random incidence sound absorption coefficients estimated directly from the reverberation time measurements and the coefficients computed from normal incidence measurements. This is because the estimation of random incidence from normal incidence is based on a direct empirical approach, by measuring α_n and α_{ran} and relating these two parameters for a number of materials with similar properties. This method of approach seems to give very low values of α_{ran} at low frequencies and approaches α_{rev} at very high frequencies. The maximum numerical difference could be of the order of 0.15 to 0.20, as has been reported in ASTM Standards.

The random absorption coefficient, as reported by the manufacturer, is replotted in comparison with the present tests in Figure 5. Both the results were computed from normal incidence measurements. The present results show on an average 10-15% lower absorption coefficients than those reported by the manufacturer. However, as only limited tests were conducted, a firm conclusion cannot be established.

As the present (6-ft × 4-ft) sample of polyurethane foam tested was smaller than the standard sample (9-ft × 8-ft), one may expect significant diffraction effects. Northwood's curves for correcting for diffraction effects were limited to a relatively small range of values of b, g, and Ka. The curves had to be extrapolated for estimating these effects beyond the range presented.

The liquid soap foam results show highly promising acoustical absorption qualities. The 1-in thick foam shows a wavy pattern of absorption with a marked peak at 600 c/s. One possible explanation for this marked peak is quarter wavelength resonance. The impedance tube measurements on the liquid soap foam of different densities (Ref. 2) support this view.

One may (Fig. 3) see a significant change in the absorption qualities of 2-in thick liquid soap foam after a 1/2-hr drainage. This is presumably due to the reduction in the density of the soap foam, resulting in a longer wavelength of the sound inside the foam.

The effects of diffraction on the random absorption coefficient of 4-in thick liquid soap foam is not expected to be very serious, as bigger samples of the foam were tested. One may reasonably guess a value of 8-10% increase in the absorption coefficients in the intermediate frequency range.

6.0 CONCLUSIONS

1) The 2-in thick polyurethane foam had a normal incidence sound absorption coefficient of 0.39 at 500 c/s, increasing to 0.91 at 1750 c/s.

2) Reverberation time measurements showed a random incidence absorption coefficient of 0.79 at 500 c/s to 1.0 at 1250 c/s with corrections for the effects of diffraction.

3) Random incidence absorption coefficients computed from impedance tube measurements showed marked differences with reverberation time measurements.

4) Liquid soap foams showed high sound-absorbing capabilities. A 4-in thick liquid soap foam layer had a random incidence coefficient ranging from 0.72 at 300 c/s to 1.0 at 800 c/s (without diffraction corrections).

5) A 1/2-hr drainage showed a marked reduction in the sound-absorption capacity with 2 in of liquid soap foam.

In view of the relatively small number of tests carried out, the above results may not be regarded as conclusive. Further tests would be necessary to quantitatively establish the absorption coefficients.

7.0 REFERENCES

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2. Macaulay, G.A. — Some Experiments on Acoustic Absorption in Liquid Foams. NRC, Mech. Eng. Report (to be published).

3. Tentative Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms. ASTM Standards, American Society of Testing of Materials, November 1966.

4. Zwikker, C.S.; Kosten, C.W. — Sound Absorbing Materials. Elsevier Press Inc., 1949.

5. Northwood, T.D. — Absorption of Diffuse Sound by a Strip or Rectangular Patch of Absorptive Materials. NRC, DBR No. 44, National Research Council of Canada, April 1964.

TABLE 1

IMPEDANCE MEASUREMENTS OF 2-INCH THICK POLYURETHANE FOAM

Frequency	Resistance R	Reactance X
250	0.2	-1.3
400	0.65	-0.9
500	0.60	-0.8
750	0.60	-0.60
1000	0.60	-0.50
1250	0.60	-0.30
1500	0.60	0
1750	0.70	0
2000	0.60	0

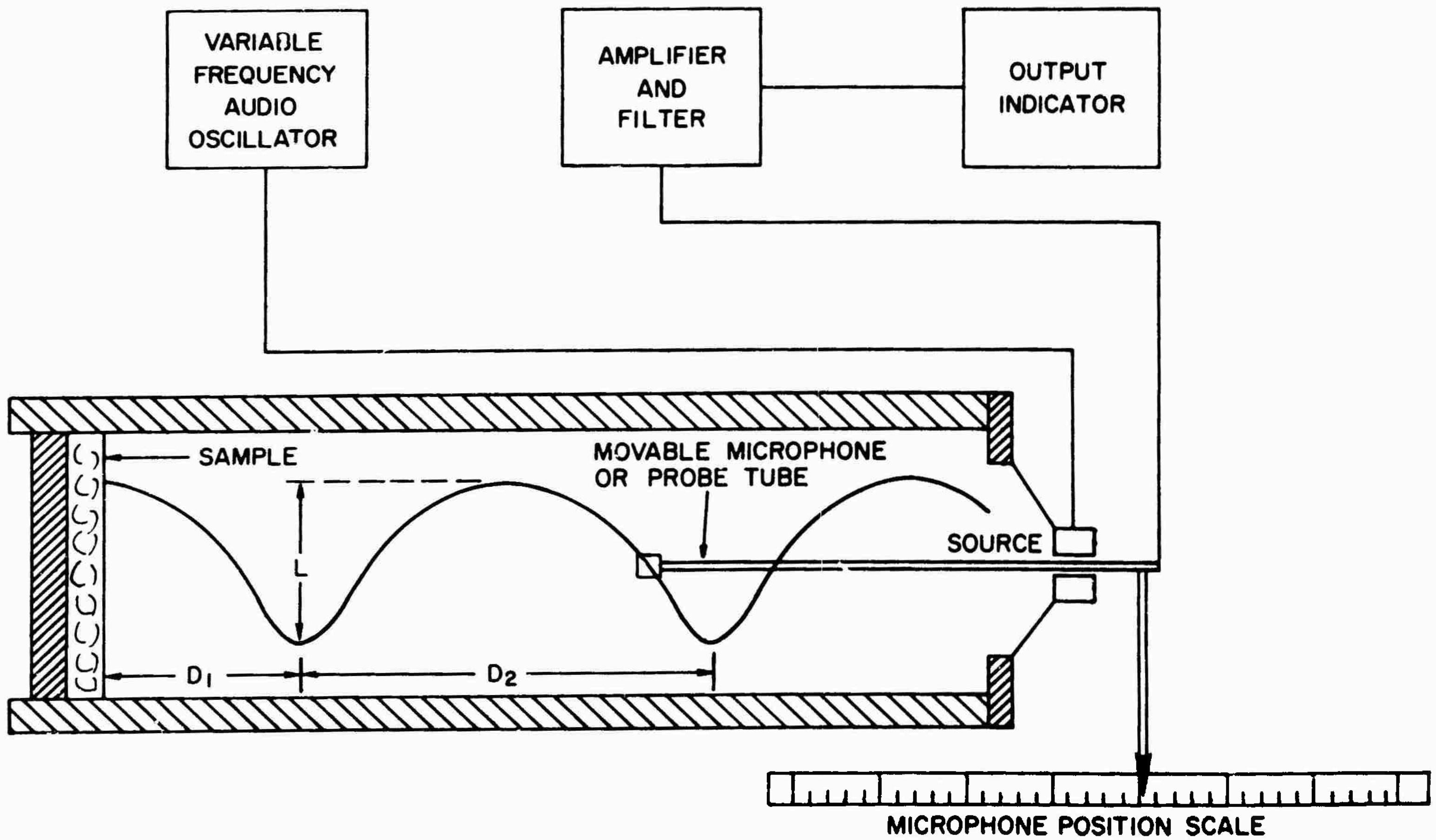

FIG. 1: IMPEDANCE TUBE

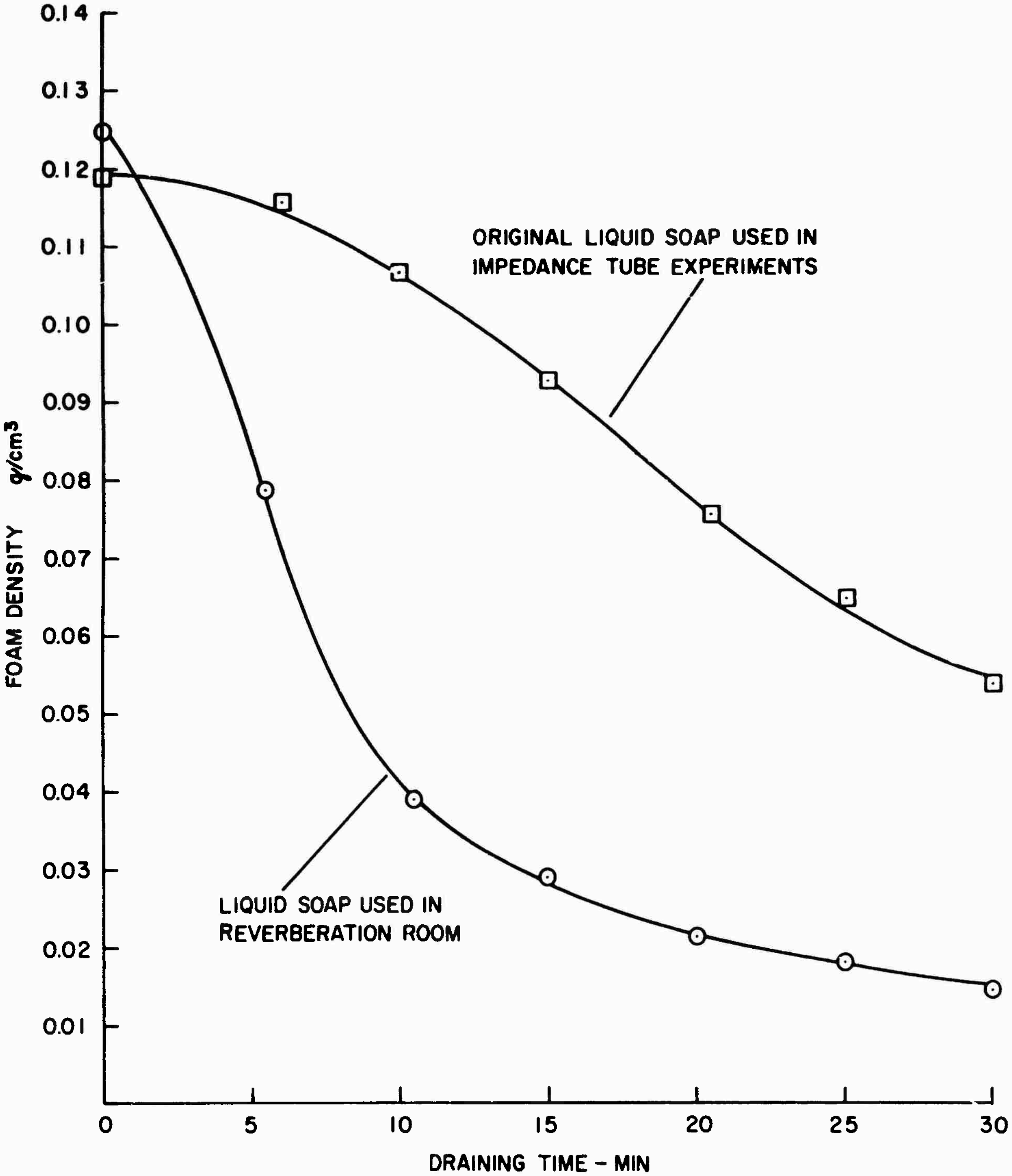

FIG. 2: DRAINING RATE OF 1:1 WATER: LIQUID SOAP FOAMS

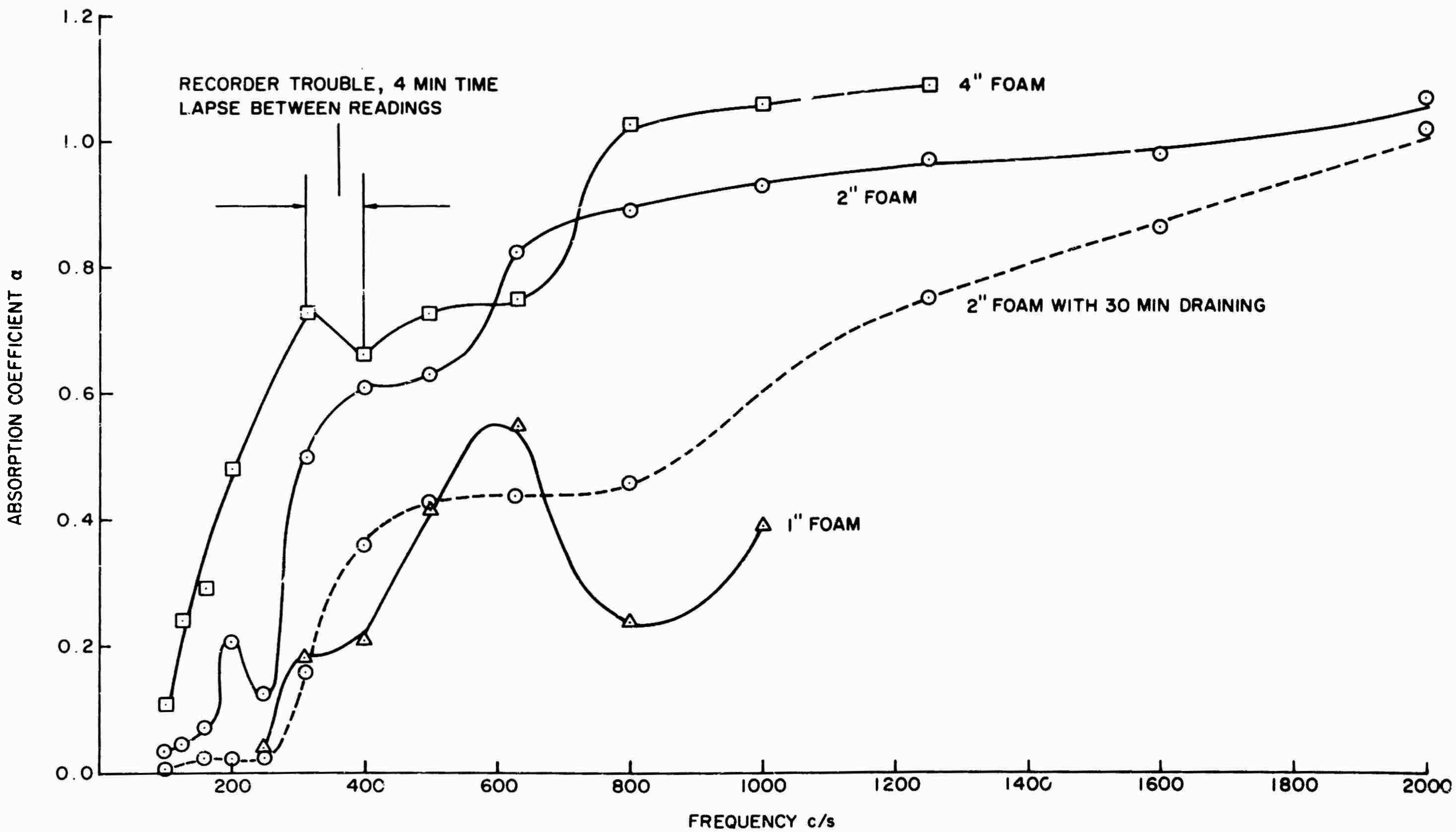

FIG. 3 : ABSORPTION COEFFICIENT OF LIQUID FOAMS BY REVERBERATION TIME MEASUREMENTS

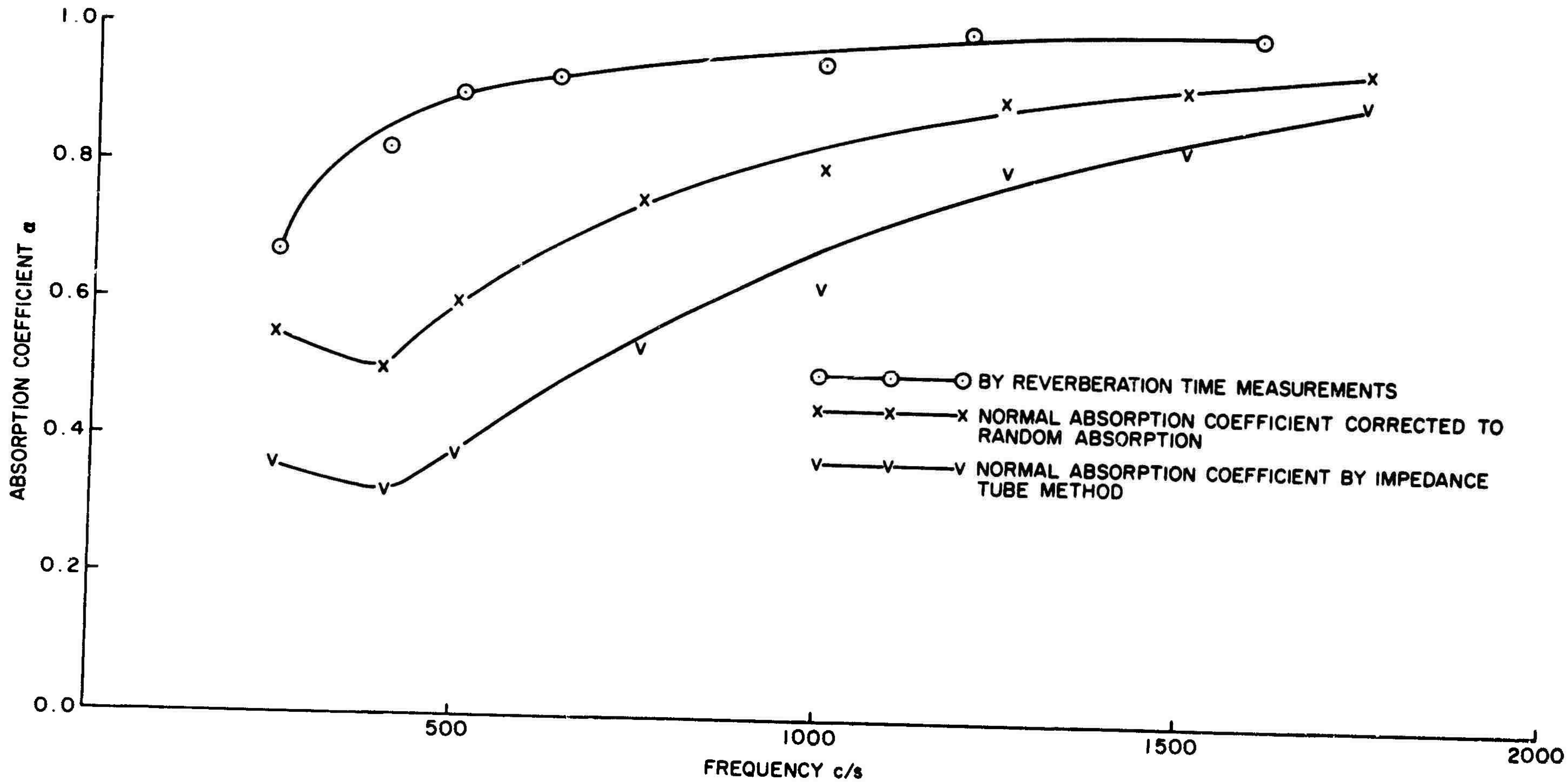

FIG. 4: ABSORPTION COEFFICIENT OF 2-INCH POLYURETHANE FOAM

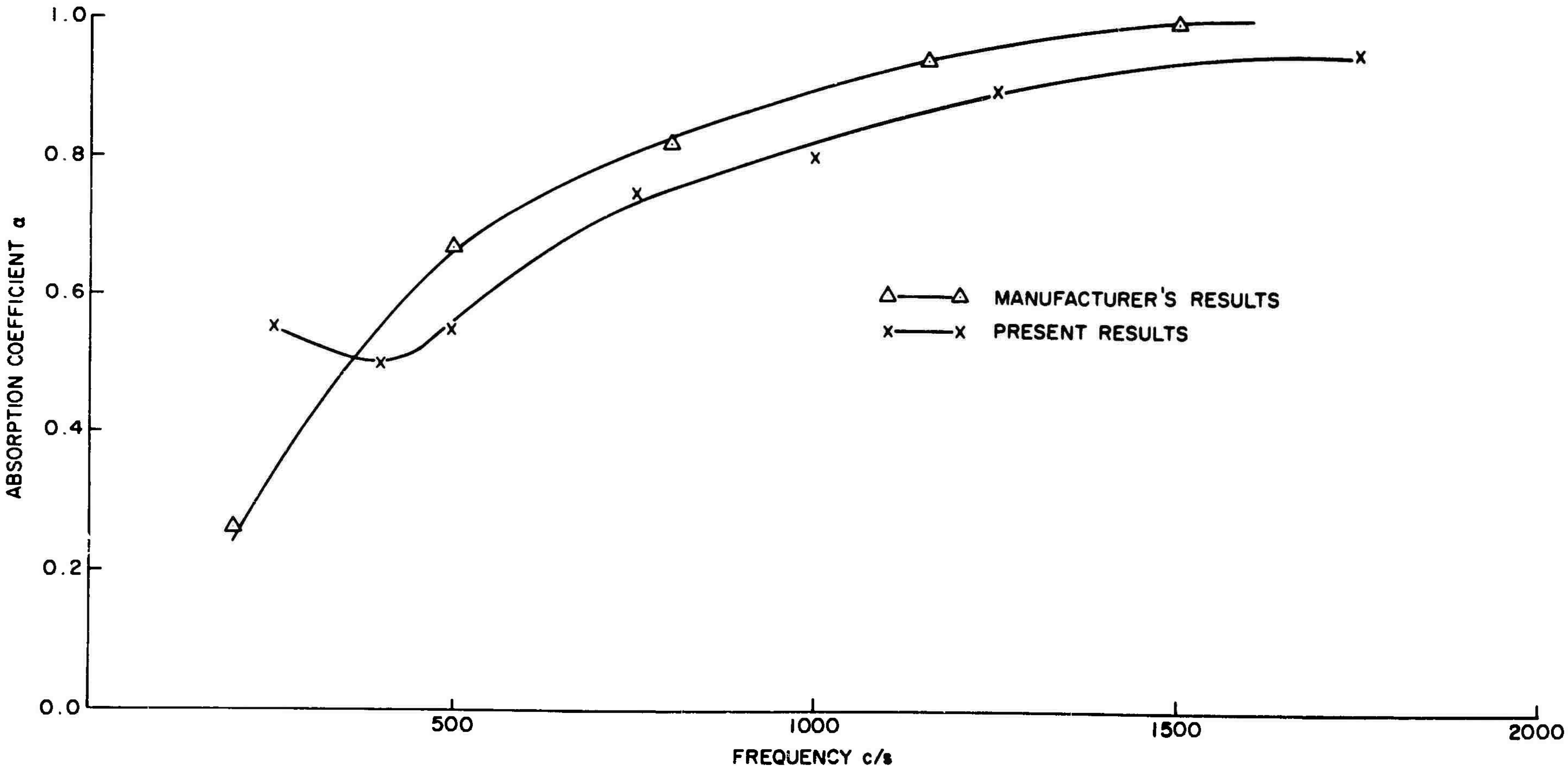

FIG. 5: COMPARISON OF ABSORPTION COEFFICIENT MEASUREMENTS